INDUSTRIAL ENERGY USE INDICES

A Thesis

by

ANDREW HANEGAN

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

December 2007

Major Subject: Mechanical Engineering

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Approved by:

Chair of Committee,	Warren Heffington
Committee Members,	Dan Turner
	Tom Wehrly
Head of Department,	Dennis O'Neal

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ABSTRACT

Industrial Energy Use Indices. (December 2007)

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Chair of Advisory Committee: Dr. Warren Heffington

Energy use index (EUI) is an important measure of energy use which normalizes energy use by dividing by building area. Energy use indices and associated coefficients of variation are computed for major industry categories for electricity and natural gas use in small and medium-sized plants in the U.S. The data is very scattered with the coefficients of variation (CoV) often exceeding the average EUI for an energy type. The combined CoV from all of the industries considered, which accounts for 8,200 plants from all areas of the continental U.S., is 290%. This paper discusses EUIs and their variations based on electricity and natural gas consumption. Data from milder climates appears more scattered than that from colder climates. For example, the ratio of the average of coefficient of variations for all industry types in warm versus cold regions of the U.S. varies from 1.1 to 1.7 depending on the energy sources considered.

The large data scatter indicates that predictions of energy use obtained by multiplying standard EUI data by plant area may be inaccurate and are less accurate in warmer than colder climates (warmer and colder are determined by annual average temperature weather data). Data scatter may have several explanations, including climate, plant area accounting, the influence of low cost energy and low cost buildings used in the south of the U.S.

This analysis uses electricity and natural gas energy consumption and area data of manufacturing plants available in the U.S. Department of Energy's national Industrial Assessment Center (IAC) database. The data there come from Industrial Assessment Centers which employ university engineering students, faculty and staff to perform energy assessments for small to medium-sized manufacturing plants. The nation-wide IAC program is sponsored by the U.S. Department of Energy.

A collection of six general energy saving recommendations were also written with Texas manufacturing plants in mind. These are meant to provide an easily accessible starting point for facilities that wish to reduce costs and energy consumption, and are based on common recommendations from the Texas A&M University IAC program.

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DISCLAIMER

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CHAPTER I

INTRODUCTION

INDUSTRIAL BENCHMARKING

The practice of using various types of energy use indices (EUIs) for benchmarking purposes in commercial buildings has been a common practice for many years [1,2,3]. It has not been until more recently, however, that these types of metrics have started to be considered for use in the industrial sector. EUIs relate the energy used in a particular facility or group of facilities to a number of measurable quantities on a per unit basis. These are most commonly based on things such as gross annual sales, production units, degree days and plant area [4]. A plant that has historical EUI data, or EUIs from plants in a similar industry, can use this information to evaluate its current performance and set goals for future energy management. Using general types of these indices can have pitfalls, however, which will be discussed in detail in later sections.

In addition to these metrics themselves being useful to the facilities, the act of plant personnel going through the process of creating these indices and composing the related reports can also be of benefit. As Wayne Turner suggests, “The report is probably of most value to the one that prepares it. It is a forcing function that requires all information to be pulled together in a coherent manner. This requires much thought and analysis that might not otherwise take place.” [5]. Having people dedicated to gathering the information required to produce these indices on an individual plant level can often cause them to start thinking in terms of plant energy reduction and possible future

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This thesis follows the style of Energy.

projects.

There are several excellent examples of EUI type benchmarking tools that have been developed. Some of these have been for specific industries, while others take a more general approach. This includes work that has been done at the Lawrence Berkeley National Laboratory, in conjunction with Fetzer Vineyards, in creating a benchmarking program for use in the California wine industry [6], the resources available from Energy Star for the cement manufacturing, corn refining, and motor vehicle manufacturing sectors [7], and the US Department of Energy sponsored Quick Plant Energy Profiler (QuickPEP) [8].

The Benchmarking and Energy and water Savings Tool (BEST) Winery program was developed by Lawrence Berkley National Laboratory and Fetzer Vineyards. This Microsoft Excel™ based instrument provides a way for individual wineries to evaluate their energy efficiency compared to a similar, hypothetical, winery that employs best practices and which is used as a benchmark. This program takes the differences in product mixes, as well as other characteristics of the winery, into account and produces a meaningful energy intensity index (EII). This EII is 100 times the ratio of the winery's energy intensity to that of the benchmark's. A winery that is operating at its best energy efficiency would have an EII of 100, and values over 100 indicate room for improvement. The BEST Winery tool also provides an estimate of the facilities electrical energy and cost savings should improvements be made [6].

Since 1992 the Energy Star program, a joint effort of the U.S. Environmental Protection Agency and the U.S. Department of Energy, has been helping consumers and businesses save money and reduce greenhouse gas emissions a number of ways [8].

More recently, they have focused some of their attention on providing energy management techniques that help in measuring energy performance, setting goals, tracking savings, and rewarding improvements in manufacturing facilities [9].

In addition to the tools provided for specific industries, such as coordinating meetings of industry energy managers, information sharing sessions, and providing energy efficiency guides, EPA has also started an industrial benchmarking program. While the energy efficiency guides are currently available for eight specific industries, they have also compiled "Energy Performance Indicators" (EPI) for three industries to date, cement manufacturing, corn refining, and motor vehicle manufacturing [7]. These EPIs are benchmarking programs for specific industries and provide a benchmark based on a multitude of variables from the actual production system. These programs were created based on information obtained from non-public U.S. Census Bureau data and by working directly with plant managers in the specific industries. The EPI that is provided allows plant managers the ability to see where they stand in relation to other facilities in their industry and set goals accordingly [7]. By being very specific in their benchmarking, using evaluations down to the level of the actual processes in the plant, the Energy Star systems are able to avoid some of the pitfalls of using very broad data. While there are currently only three of these EPI programs available, more are being produced.

One other program of note that is currently available is the Quick Plant Energy Profiler (QuickPEP). This web-based tool was developed by the Department of Energy and is meant to be a very general, very broad, look at plant energy consumption. Using the tool requires that the plant's various forms of utility data be entered, followed by some general production information. Once this is complete the person running the program is asked a few questions about the energy management policies and steps that have been taken to reduce energy use and waste. Based on the inputs, results are then given that show very rough approximations of energy savings and also, more importantly, steps that can be taken to reduce energy consumption. This is meant to be a first step in energy reduction at a facility and provides good starting points [10]. The energy savings calculations in QuickPEP, however, depend on some sort of general, industry specific, energy consumption data and estimates of the energy consumed by each system in the facility as a percentage of total energy consumed by the plant. The variability in this data could be quite large, which may cause the values of the actual savings potential to vary widely from what the program predicts.

MOTIVATION

The initial purpose of this project was to test the hypothesis that the variability in energy use index (EUI) for similar industries in the southern part of the United States is greater than in the north. Many industrial buildings in the north are constructed primarily of masonry. In the south, less expensive, uninsulated, sheet metal curtain-wall construction supported by a steel frame is common. Large apertures or even the south wall are left open year round or almost year round. In the south, more work can be done outdoors or in similar conditions due to the milder climate, even in winter. The less expensive construction and associated lower land use costs lead to lessened emphasis on minimizing building area. Thus there may be less care given in the south to both construction area and eventual accounting for that area, leading to more scatter in the

EUI. For the purposes of this report, EUI is defined as the amount of energy[1] a facility consumes annually per square foot of plant area at the production site. For a building with area A, the EUI for electrical energy consumption (EUI_{El}) is

$$EUI_{El} = \frac{E_{El}}{A} \tag{1}$$

where E_{El} is the annual electrical energy consumption converted into millions of British thermal units (MMBtu). The EUI for natural gas consumption (EUI_{NG}) is

$$EUI_{NG} = \frac{E_{NG}}{A} \tag{2}$$

where E_{NG} is the annual natural gas energy consumption also in MMBtu. The combined EUI_C will be

$$EUI_C = EUI_{El} + EUI_{NG} = \frac{E_{El} + E_{NG}}{A} \tag{3}$$

As the study of the initial hypothesis progressed, the overall large variation in the data came to be of interest. EUI data is often used as a benchmark for commercial and institutional buildings [2,3]. The variability noted in the industrial EUI data considered in this paper, however, makes its use for benchmarking problematic. The following sections of this report will detail the methods used to assess the variability in the EUI data and present the results of the study.

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[1] In this thesis, all energy consumption values used are <u>site</u> values, that is, the energy actually consumed at the site of the facility. There are no allowances to correct for generation or production losses of the energy to the site of use. Such corrections result in <u>source</u> values.

DATA SOURCE

The data used in this analysis was taken from the database maintained at the IAC field manager’s office located at Rutgers University [11]. Information is available from over 13,000 energy assessments done by the various IAC centers mostly on small to medium sized manufacturing plants. Presently, the IAC program guidelines for small to medium sized plants call for less than $2 million annually in energy costs and specify that each plant will meet three of the following four criteria: under $100 million in gross annual sales, fewer than 500 employees, no in-house energy expertise, and more than $100,000 per year in utility costs [12]. Table 1 summarizes the universities and locations of the individual centers used in this study as well as their corresponding average annual temperatures from NOAA data [13]. The centers in Table 1 have not all been operational the same length of time. Some are relatively new compared to others, and some are defunct.

IAC assessment visits generally take one day and are conducted by teams of university students professionally led by a university engineering faculty or staff member. Assessment activities include requesting and analyzing 12 months of energy consumption data for major energy sources used by the plants. Energy consumption data usually is supplied as copies of monthly bills which typically only consist of the site energy consumption for the plant, and not the energy consumption at the source. Occasionally, when 12 months of data are not available, fewer months of data may be used to estimate annual consumption. The plant manufacturing area size may either be supplied by a knowledgeable plant contact (sometimes from memory) or may be measured by IAC personnel during the visit. Office, break room, personnel locker and restroom areas, and warehouse area may or may not be included.

Table 1: IAC Locations and Temperature Data

School Name	City	State	Average Temp (°F)
South Dakota State University	Brookings	SD	45.1
University of Maine	Orono	ME	45.7
University of Wisconsin	Madison	WI	46.1
University of Massachusetts	Amherst	MA	47.2
Syracuse University	Syracuse	NY	47.4
University of Illinois	Chicago	IL	49.1
University of Michigan	Ann Arbor	MI	49.7
Notre Dame University	Notre Dame	IN	49.9
Iowa State University	Ames	IA	50.0
Colorado State University	Fort Collins	CO	50.1
Lehigh University	Bethlehem	PA	50.6
Bradley University	Peoria	IL	50.8
West Virginia University	Morgantown	WV	50.9
University of Nevada	Reno	NV	51.3
University of Dayton	Dayton	OH	51.5
University of Utah	Salt Lake City	UT	52.0
Hofstra University	Hempstead	NY	52.4
Oregon State University	Corvallis	OR	52.6
University of Missouri	Columbia	MO	54.0
University of Kansas	Lawrence	KS	54.3
University of Louisville	Louisville	KY	56.9
San Francisco State University	San Francisco	CA	57.3
University of Tennessee	Knoxville	TN	58.4
North Carolina State University	Raleigh	NC	59.6
Old Dominion University	Norfolk	VA	59.6
Oklahoma State University	Stillwater	OK	60.8
Mississippi State University	Starkville	MS	61.3
University of Arkansas	Little Rock	AR	62.1
Georgia Tech	Atlanta	GA	62.1
Loyola Marymount	Los Angeles	CA	63.3
San Diego State University	San Diego	CA	64.4
University of Louisiana	Lafayette	LA	67.0
University of Texas	Arlington	TX	68.5
University of Florida	Gainesville	FL	68.6
Texas A&M University	College Station	TX	68.7
Texas A&M Kingsville	Kingsville	TX	71.5
Arizona State University	Tempe	AZ	74.2
University of Miami	Coral Gables	FL	75.3

Included in the database are the plant size, annual site energy consumption and cost, principal manufacturing products, as well as identification of the center that performed the assessment and the date that the facility was visited. On average, the plants that are visited have a floor area of about 200,000 square feet and gross annual sales of approximately $300,000. This resource is available in web-based or downloadable forms from the Rutgers IAC website [11]. For this report, the data was downloaded and analyzed in Microsoft Access™.

CHAPTER II

ANALYSIS

METHODOLOGY

There is a large amount of industrial energy consumption and other plant data in a database of plant assessment visits [11]. The data is from U.S. Department of Energy-funded industrial energy assessments performed by university-based Industrial Assessment Center (IAC) teams covering all areas of the U.S. [14].

To evaluate the variation in the data, the average EUI was calculated for the individual IAC centers and the plants that they had visited. These industrial plants were grouped by the first two digits of their standard industrial classification (SIC) industrial code, and the standard deviation was calculated using Eq. 4 below for the electric and natural gas EUIs individually.

$$s_i = \sqrt{\frac{1}{N-1} \cdot \sum_{j=1}^{N} \left(EUI_{i,j} - \overline{EUI}_i \right)^2} \tag{4}$$

where s_i is the standard deviation of the sample for the i^{th} energy type, i representing either electricity or natural gas; N is the number of plants being considered; $EUI_{i,j}$ is the EUI for the i^{th} energy type for a specific plant j; and $\overline{EUI}_i$ is the average EUI for the i^{th} energy type for the N plants being considered.

For the combined EUI data, which is the total of the electric and natural gas EUIs for a specific plant, Eq. 5 was used to calculate the standard deviation.

$$s_C = \sqrt{\frac{1}{N-1} \cdot \sum_{j=1}^{N} \left(EUI_{C,j} - \overline{EUI}_C \right)^2} \tag{5}$$

where s_C is the standard deviation of the sample for the combined case, N is the number of plants being considered, $EUI_{C,j}$ is the combined EUI from Eq. 3, and $\overline{EUI}_C$ is the average of the combined EUIs being considered.

The data was grouped accordingly and Chauvenet's criterion was employed to eliminate extreme outliers. Chauvenet's criterion is based on a normal statistical distribution. Since the data used in this study are not normally distributed, the variances presented in this paper likely underestimate the actual variance, and the true variation may even be more than what is shown here. The coefficient of variation (CoV), which is simply the standard deviation divided by the average EUI, for each industry was then determined. Using this data, comparisons were made between five of the IAC centers with the coldest average annual temperatures and five of the centers with the warmest temperatures. Temperature data was taken from the National Oceanic and Atmospheric Administration weather data [13]. These calculations were done without separating the individual IAC centers and only grouping the plants by their two digit SIC codes. This allowed a comparison of the average CoV for different industries in the cooler and warmer states without giving weight to individual centers because the centers did not each visit the same number of plants in a given category. Similarly, all thirty-eight IAC centers that had data available were divided into the nineteen colder centers and nineteen warmer centers, based on their average temperatures, and the ratio of their CoVs was determined.

The IAC database has data with SIC numbers back to 1981 [11]. In 2002 data based on the North American Industrial Classification System (NAICS) began to be included, and this also was used to evaluate the variation in the data. This reduced the number of plants available for analysis by about 86% because only those assessments that had been done since the NAICS code's implementation could be used. Since the number of plants that could be considered became so small, the data associated with this code system was only used for general, overall, comparisons. Table 2 summarizes the major SIC codes used in this analysis and their NAICS counterparts.

Table 2: SIC and NAICS Codes

NAICS Code	SIC Code	Description
-	20	Food and Kindred Products
311	-	Food Manufacturing
312	-	Beverage and Tobacco Product
313	22	Textile Mill Products
315	23	Apparel And Other Finished Fabric Products
321	24	Lumber And Wood Products, Except Furniture
337	25	Furniture And Fixtures
322	26	Paper And Allied Products
323	27	Printing, Publishing, And Allied Industries
325	28	Chemicals And Allied Products
324	29	Petroleum Refining And Related Industries
326	30	Rubber And Miscellaneous Plastics Products
327	32	Stone, Clay, Glass, And Concrete Products
331	33	Primary Metal Industries
332	34	Fabricated Metal Products, Except Machinery And Transportation Equipment
333	35	Industrial And Commercial Machinery And Computer Equipment
-	36	Electronic And Other Electrical Equipment And Components, Except Computer Equipment
334	-	Computer and Electronic Product Manufacturing
335	-	Electrical Equipment, Appliance, and Component Manufacturing
336	37	Transportation Equipment
-	38	Measuring, Analyzing, Controlling Instruments; Photographic, Medical, Optical Goods; Watches
339	39	Miscellaneous Manufacturing
511	-	Publishing Industries (except Internet)

RESULTS

This section presents a summary of the data used to draw conclusions about the magnitude of the CoVs on the whole, as well as the differences in variation between warmer and cooler states. The conclusions that can be made from this data will be presented in the next section.

Tables 3 and 4 show the average site EUI, CoV, and total number of assessments performed for all of the plants in each specific industry. These are also divided into electrical, natural gas, and combined energy usage categories. The industries in Table 3 are based on the first two digits of the plant's SIC code, while Table 4 is based on the three digit NAICS code for the facility's principal products (see Table 2 for SIC and NAICS code descriptions). Site EUIs in the latest commercial building energy conservation survey varied from 0.004 MMBtu/sf for self-storage buildings to 0.53 MMBtu/sf for fast food establishments [3]. The combined values in Table 3 vary from 0.12 MMBtu/sf for furniture and fixtures manufacturing (SIC 25) to 4.60 MMBtu/sf for petroleum refining and related industries (SIC 29).

Table 5 shows the ratio of the average CoV for five centers with higher temperatures in Table 1 to the average CoV for five centers with colder temperatures based on the first two digits of the plant's SIC code. The warmer centers are Arizona State University, Texas A&M University, the University of Florida, San Diego State University, and the Georgia Institute of Technology. The cooler centers are the University of Wisconsin, the University of Massachusetts, the University of Michigan, Iowa State University, and Colorado State University. These centers were selected because they had a larger number of assessment visits than some of the other centers in Table 1 with more extreme temperatures.

This analysis was repeated simply to contrast the nineteen centers with warmer temperatures to the nineteen centers with colder temperatures. This division falls between the University of Missouri and the University of Kansas in Table 1, and these results are summarized in Table 6.

Table 3: Calculated Site EUIs and CoVs Based on Two Digit SIC Codes

	Electric		Natural Gas		Combined		
Industry	EUI (MMBtu/sf)	CoV (%)	EUI (MMBtu/sf)	CoV (%)	EUI (MMBtu/sf)	CoV (%)	# Plants
20	0.20	92	0.33	190	0.55	115	943
22	0.22	131	0.26	163	0.50	96	230
23	0.08	72	0.13	227	0.20	156	146
24	0.15	167	0.12	371	0.28	254	379
25	0.06	103	0.06	191	0.12	111	232
26	0.13	110	0.18	240	0.33	165	475
27	0.12	57	0.06	194	0.18	78	346
28	0.21	169	0.34	255	0.66	231	381
29	0.21	291	4.29	316	4.60	297	69
30	0.21	82	0.08	219	0.31	77	956
32	0.17	135	0.65	170	0.85	146	300
33	0.21	86	0.43	196	0.65	97	576
34	0.11	81	0.15	311	0.27	114	1,094
35	0.09	75	0.08	157	0.18	81	858
36	0.15	86	0.07	223	0.22	88	463
37	0.12	88	0.08	240	0.20	92	418
38	0.14	163	0.06	163	0.20	145	182
39	0.07	118	0.10	139	0.17	108	130

Table 4: Calculated Site EUIs and CoVs Based on Three Digit NAICS Codes

	Electric		Natural Gas		Combined		
Industry	EUI (MMBtu/sf)	CoV (%)	EUI (MMBtu/sf)	CoV (%)	EUI (MMBtu/sf)	CoV (%)	# Plants
311	0.19	117	0.35	185	0.57	147	207
312	0.18	99	0.13	85	0.32	77	26
313	0.23	60	0.19	121	0.39	63	25
315	0.10	85	0.05	187	0.26	110	17
321	0.20	112	0.17	243	0.36	141	68
322	0.19	166	0.24	250	0.42	191	90
323	0.15	64	0.14	139	0.27	99	35
324	0.07	156	0.76	183	3.68	399	24
325	0.20	121	0.37	257	0.58	196	104
326	0.27	89	0.07	153	0.36	78	178
327	0.15	123	0.57	172	0.70	141	50
331	0.22	118	0.41	267	0.65	174	114
332	0.12	79	0.18	138	0.31	100	232
333	0.11	94	0.07	109	0.18	80	133
334	0.17	73	0.07	162	0.23	85	56
335	0.17	107	0.25	188	0.36	139	37
336	0.14	95	0.09	135	0.23	87	122
337	0.06	107	0.09	193	0.14	145	54
339	0.15	106	0.14	146	0.28	98	57
511	0.12	36	0.04	99	0.17	44	23

Table 5: Ratio of Average CoV for Five Higher Temperature Centers to that for Five Lower Temperature Centers by SIC

Industry	Combined	Electricity	Natural Gas
20	1.07	1.36	1.66
22	0.83	1.79	0.76
23	0.75	0.64	1.14
24	2.43	1.36	3.33
25	0.98	0.68	1.17
26	0.40	0.62	0.60
27	1.48	0.88	2.86
28	2.78	1.61	1.37
29	1.94	0.96	1.84
30	1.42	1.25	1.57
32	0.34	0.39	0.77
33	0.82	1.62	0.83
34	1.09	1.19	1.54
35	1.89	1.21	4.02
36	1.35	0.98	1.73
37	1.02	0.96	1.43
38	1.45	1.66	1.09
39	1.03	0.76	2.44
Average	1.28	1.11	1.67

Table 6: Ratio of Average CoV for Nineteen Higher Temperature Centers to that for Nineteen Lower Temperature Centers by SIC

Industry	Combined	Electricity	Natural Gas
20	0.85	0.94	0.93
22	0.73	1.52	0.72
23	0.62	0.84	0.87
24	0.97	1.18	1.04
25	0.97	1.49	0.98
26	0.46	0.56	0.53
27	1.04	0.89	1.56
28	0.65	0.74	1.13
29	2.38	1.05	2.40
30	1.15	1.01	1.60
32	0.86	1.34	0.92
33	1.03	1.01	0.99
34	1.40	1.10	1.75
35	1.08	1.07	1.03
36	1.03	0.98	1.15
37	0.90	1.08	1.07
38	2.11	2.41	1.25
39	1.12	1.36	1.04
Average	1.07	1.14	1.16

DISCUSSION OF RESULTS

Examining the data in the previous section in Tables 3 and 4 one can see that the CoVs for the individual industries are large, often exceeding 100%, which indicates that the standard deviation in the data is larger than the average. These variations may be extremely large with some CoVs in the 200% to 300% range, meaning that the standard deviation is two or three times the average. The overall magnitude of these CoVs is an important consideration when using data of this type for benchmarking purposes. Such large variations indicate that simply using the EUI data as a baseline for energy usage in a specific industry may not be a reasonable approach. Some of the possible reasons for these large variations will be discussed later in this section.

Greater variation in EUIs and CoVs in Tables 3 and 4 occurs in the natural gas data compared to the electricity data. For example, in Table 3, the CoV for electricity varies from 57% to 291% and averages 117%. For natural gas, the CoV varies from 170% to 371% and averages 220%. Table 4 reflects this same trend.

Comparing the variations in the warmer and cooler states in Table 5, the ratios of the combined CoVs for the warm to cool states are mostly above one for the individual industries and averages 1.28. This indicates that, for the centers in the states that were chosen, those in the warmer climates had more variation in their data than those in the cooler climates. Likewise, the ratios for either electricity or natural gas are often above one. This is only an indication because the CoVs in Table 5 and Table 6 are so large. To better test the hypothesis that the southern states have more variation in their energy use intensity than the northern states different data with less variation should be used.

There are several factors that could contribute to the large variations in the data used for this analysis. The first of these is that some SIC codes that were used in this study are very broad, often containing industries that produce the same kinds of products, but having very different energy consumption needs. An example is SIC Major Group 33, primary metal products, which has industries ranging from aluminum die casting plants (SIC 3363) to steel works, blast furnaces and rolling mills (SIC 3312) [15]. While both make primary metal products, those industries in SIC 3363 are generally much more energy intensive than those in SIC 3312. The average combined EUI is 0.80 MMBtu/sf for SIC group 3363 and 0.46 MMBtu/sf for SIC 3312. Differences like this could contribute to the large overall variations for the specific industries. These types of trends were also noticed by Niranjan Hiras when previously working with IAC data. He observed in his report, ”Each industry that is audited is unique in nature. Neither the products nor the processs (or the equipment) of any two industries are similar.” [16]

Narrowing the analysis to more specific industrial groups reduces the amount of variation present. For example, expanding Table 4 from three to four digit NAICS Codes reduces the average combined CoV from 125% to 100%. Likewise, evaluating four digit NAICS codes beginning with (332_) yielded an average CoV of 83%, while an analysis with five and six digit 332 codes (332_ _ and 332_ _ _) produced CoVs of 81% and 69%, respectively.

Other possible factors involve the reporting of area and energy data in the database. The plant area is often provided by plant personnel on the day of the assessment, and the energy consumption data is taken from the plant’s utility bills, both of which can have errors associated with them. Often if much of the plant's production area is outdoors and uncovered, what will be documented is only the enclosed area under roof. If this area is reported in the database it can artificially inflate the overall EUI of the plant. The energy use data is also a potential source of error. The utility figures in the database are the annual energy consumption; however, sometimes it is estimated based on less than twelve months of data. This could also increase or decrease the calculated EUI for the plant. Finally, there is always a possibility of input errors when the information is being loaded into the database. This could result in the EUI datum differing from its true value just because a number was entered incorrectly when the plant statistics were being loaded.

OTHER RESEARCH

Two undergraduate students also did some research pertaining to EUIs. Instead of normalizing the energy consumption based on plant area, however, the EUIs calculated were based on production units as shown in Eq. 6 below,

$$EUI = \frac{E}{P} \tag{6}$$

where E is the energy of some type (electricity, natural gas or other), and P is the number of production units. This was done mainly for two reasons. The first was to determine if less scatter would be present because of the possible increase in accuracy using more reliable production data. In the IAC database, the production units at any given plant are usually more closely monitored and recorded than the plant manufacturing area. Additionally, this was done to see if the same decrease in the variation was apparent as the industries became more specific. One student studied SIC codes 24 (lumber and wood products, except furniture) and 30 (rubber and miscellaneous plastics products), and the other 34 (fabricated metal products, except machinery and transportation equipment) and 35 (industrial and commercial machinery and computer equipment). Of the two industries each student was provided, one had shown a relatively small variation and the other a large variation in the area-based EUIs studied previously. All four categories also all had a rather large number of plants. This was done so that the results obtained for each industry would be more reliable.

Upon completion of their research, similar trends compared to the area-based EUIs were seen. The CoV values on the whole were very large, and as the industrial classification became more specific the variation in the data decreased. Table 7 below illustrates their findings.

Table 7. Combined Average EUIs and CoVs for SIC Codes 24, 30, 34 and 35

Industry	Average EUI (MMBtu/ton)	CoV (%)	Average EUI (MMBtu/ 1,000 Feet)	CoV (%)
Two Digits, 24	1,490	153	13,000	635
Three Digits, 24x	1,670	135	7,630	368
Four Digits, 24xx	1,350	122	9,440	219
Two Digits, 30	160,000	972	1,610,000	201
Three Digits, 30x	122,000	433	2,060,000	182
Four Digits, 30xx	230,000	169	1,870,000	132
Two Digits, 34	74.4	903	13.04	221
Three Digits, 34x	69.34	144	7.81	74
Four Digits, 34xx	54.07	106	7.70	66
Two Digits, 35	40.5	292	19.85	229
Three Digits, 35x	19.44	118	19.85	77
Four Digits, 35xx	25.94	82	19.85	77

CHAPTER III

TEXAS TIP SHEETS

OVERVIEW

Upon completing the work presented in the previous sections, the opportunity presented itself to assist Texas manufacturing plants on a broad scale. Experience from IAC assessment visits revealed several, easily-implemented energy and cost reduction measures commonly seen in many facilities. The decision was made to compose six, one to two page summaries of these recommendations with the goal of making them easily accessible to the public via the internet. There are several sources for other documents like these, however the topics that were chosen were either not found in other databases, or were not as useful to plant managers in Texas due to their very general nature. The areas that were covered include sales tax abatement, paying utility bills on time, installing high bay fluorescent lighting, turning off equipment when it is not needed, correcting power factor and using skylights effectively. These measures are called "Texas Tip Sheets" and are described on the following pages. Internet sources are planned to be on the websites of the Texas A&M IAC [17] and Texas Industries of the Future [18].

SALES TAX ABATEMENT

Manufacturing facilities in Texas may be exempt from sales taxes on their utility bills.

To qualify for this tax exemption, the usage of each of the facility's utility meters must be evaluated and at least 50% of the energy that is flowing through the meter must go directly to manufacturing operations. These "Manufacturing Operations" are described in Rule 3.295 of the Texas Administrative Code [19], and are basically anything that adds value to the product that is being produced, or that "processes tangible personal property" as the code states. Energy used in manufacturing support areas such as storage, engineering, offices, break rooms, restrooms, and showrooms are not exempt.

The required predominant use study is an analysis of twelve consecutive months of utility data for each meter. The report should include all of the uses and amounts of the energy being consumed, times of usage, and whether or not each use is tax exempt. The study must be performed by a registered engineer, or someone with an engineering degree from an accredited engineering college [19]. Once the assessment is complete, a certificate of exemption should be submitted to the utility company, and a copy of the report needs be kept onsite at the facility to ensure that no back taxes, fees, or interest are accrued should proof of the analysis be requested by the comptroller's office. Guidelines for the tax exemption certificate can be found in Rule 3.287 of the Texas Administrative Code [20].

In addition to the savings associated with avoiding the sales tax on utility bills in future months, there is also a stipulation in Rule 3.325 of the Texas Administrative Code [21] that allows for businesses to be refunded the sales tax that they have been paying for up to four years in the past. This may be a significant amount of money that can be refunded in cases where plants have historically been erroneously taxed on their utility bills.

The Texas A&M Industrial Assessment Center has recommended this tax free status to a number of small and medium-sized metal fabrication plants. Of those, 90% were able to apply for this tax exemption, and the average annual savings was $14,700.

PAY UTILITY BILLS ON TIME

Failing to pay utility bills on time can result in substantial late fees with an extremely high effective annual percentage rate (APR).

When a utility bill is not paid on time the facility is charged a late penalty. This usually some fixed percentage of the total bill and is assessed some number of days after the billing due date. An example would be a 5% penalty on the total bill which is charged three days after the bill is due. If this is paid with the next billing cycle, the facility is basically borrowing these funds from the utility company for the remainder of the month, or twenty-seven days in the example above. This results in a very high effective APR, over ninety-three percent in this case. Table 8 below shows some typical penalty percentages, the grace period given by the utility, and the resulting effective APR if the bill is paid at the due date of the next billing cycle.

Table 8: Effective APR for Various Late Fee Percentages and Grace Periods

		Grace Period (days)						
		1	*2*	*3*	*4*	*5*	*6*	*7*
Late Fee (%)	*1*	13.3	13.8	14.4	15.0	15.6	16.3	17.1
	2	28.3	29.5	30.7	32.0	33.5	35.1	36.9
	3	45.1	47.0	49.1	51.4	54.0	56.8	59.9
	4	63.8	66.7	69.9	73.4	77.3	81.6	86.3
	5	84.8	88.9	93.4	98.4	103.9	110.0	116.9
	6	108.2	113.7	119.8	126.6	134.1	142.6	152.1
	7	134.3	141.6	149.6	158.5	168.5	179.8	192.6
	8	163.4	172.7	183.0	194.6	207.6	222.3	239.2
	9	195.8	207.5	220.6	235.3	251.9	270.8	292.6
	10	231.9	246.4	262.7	281.1	302.1	326.1	353.8

While most firms pay their bills on time, common reasons late fees are incurred are that the plant's utility bills are sent somewhere off site and the payment system is not fast enough, or that the plant simply does not have the cash flow to pay them. In the latter case, ordinary loans should be acquired, if possible, which will have a significantly lower APR, to ensure that the bills are paid on time.

INSTALL HIGH BAY FLUORESCENT LIGHTING

Installing high bay fluorescent fixtures can result in energy savings from a reduction in lamp wattage as well as the ability to turn off units in areas that do not need continuous over-head lighting.

High intensity discharge (HID) lights, such as metal halide and high pressure sodium fixtures, are commonly available in wattages of 400 and 1,000 watts. Replacing these with high bay fluorescent fixtures can decrease the electrical consumption of each lamp to around 200-300 watts. Table 9 below shows the annual savings associated with replacing one HID lamp of various types and wattages with a high bay fluorescent fixture of 250 watts. Additional savings can result from lower maintenance costs in replacing the lamps in the fixtures as well. HID lamps commonly need to be replaced more often, and at a higher cost, than their fluorescent counter parts.

Table 9: Estimated Annual Energy and Cost Savings Associated with Replacing One Fixture of Various Types and Sizes[2]

Lamp Type	Wattage	Energy Reduction (kWh)	Demand Reduction (kW)	Energy Cost Savings	Demand Cost Savings	Total Cost Savings
Metal Halide	400	2,164	3	$216	$19	$236
	1,000	8,366	11	$837	$74	$911
High Pressure Sodium	400	2,409	3	$241	$19	$260
	1,000	8,979	11	$898	$74	$972

Traditional HID lamps, such as metal halide and high pressure sodium fixtures, typically require ten to fifteen minutes (“restrike” time) to regain their maximum light output after they have been shut off. Fluorescents, however, can be turned back on almost immediatley after they have been extinguished. This makes them particularly appealing for locations such as remote warehouse and storage areas that experience little traffic. Using motion sensors in conjunction with these lamps to provide lighting only when it is specifically needed can increase the energy and cost savings that these fixtures can provide.

[2] These calculations were done using a ballast allowance of 1.18, 1.25 and 0.90 for metal halide, high pressure sodium, and T8 fluorescent lamps, respectively. An average energy cost of $0.10/kWh and a demand cost of $6.50/kW were used for savings estimates.

The simple payback associated with these types of replacement projects is typically less than two years.

TURN OFF LIGHTING AND EQUIPMENT

Turning off plant equipment and lighting is one of the simplest and most cost effective methods of reducing energy consumption available. Implementation primarily is by employee education, and typically requires minimal modifications to the facility. Types of equipment that are historically on when they are not needed include such things as electric motors, lighting, and welders.

Electric motors should be turned off any time that it is practical to do so. They are able to reach their rated rotational speeds very quickly, and despite a common opinion, they do not cause significant demand spikes when they are started. Table 10 below shows the energy usage and costs for operating various sizes of electric motors for one hour and for one shift (eight hours). This table was created using an average cost of electricity of \$0.10/kWh, an average motor efficiency of 90% and an assumed load factor of 100%.

Table 10: Cost of Operating One Motor of Various Sizes for One Hour and for One Shift

Motor Size (hp)	Hourly Energy Use (kWh)	Hourly Energy Cost	Energy Use per Shift (kWh)	Energy Cost per Shift
10	8	$0.83	66	$6.63
20	17	$1.66	133	$13.26
30	25	$2.49	199	$19.89
40	33	$3.32	265	$26.52
50	41	$4.14	332	$33.16

Lighting is another source of easily obtainable energy savings. Simply turning off the lights in an area that is unoccupied, or has enough natural lighting from things such as windows, skylights, and open doors, can produce savings. Table 11 illustrates the savings associated with turning off individual, 400 and 1,000 Watt lamps for one twenty-four hour day and for one full month. This table again uses an average electricity cost of $0.10/kWh, and a ballast allowance of 10%.

Table 11: Cost of Leaving One Lamp of Various Sizes Turned On for One Day and One Month

Lamp Wattage (W)	Daily Energy Use (kWh)	Daily Energy Cost ($)	Monthly Energy Use (kWh)	Monthly Energy Cost($)
400	11	1.06	317	31.68
1000	26	2.67	792	79.20

These recommendations can be accomplished by training employees about the good practices of turning off equipment and the potential benefits. Placards and postings, which might include things like the tables above, are a useful way to educate employees to the value of turning off equipment when it is not needed.

UTILIZE SKYLIGHTS

Utilizing skylights when possible can reduce the energy costs associated with artificial lighting.

Many industrial buildings are constructed with skylights in place, however often times these are not used to their full extent. High bay lighting of various forms is usually in place to illuminate areas when the skylights would not be effective, but unfortunately these are commonly left on when full daylight is available. For the major cities in Texas, the average annual percent possible sunshine (PPS) is around 65%. This means that out of all of the days in a given year, the sun is shining bright enough for natural lighting to be used at least about 65% of the time. These are days without rain, thick clouds or fog. Table 12 below shows the annual average PPS for major cities around Texas [22], the resulting useful skylight hours, and the annual savings resulting from extinguishing one 400-Watt lamp and one 1,000-W lamp during these times. Plants usually have more than one lamp that can be turned off, and so the savings from Table 12 should be multiplied by the number of lamps that can be turned off. These calculations were made assuming a work schedule of 250 days per year, useful daylight hours from 9:00 a.m. to 3:00 p.m., an average electricity rate of $0.10/kWh and a ballast allowance of 1.10. The useful daylight hours will sometimes be longer.

Table 12: Annual Average PPS, Useful Hours, Estimated Energy and Cost Savings Associated with Using Skylights

City	Annual Average PPS (%)	Useful Hours (hrs/yr)	400-W Energy Savings (kWh/yr)	400-W Annual Savings	1000-W Energy Savings (kWh/yr)	1000-W Annual Savings
Abilene	71	1,065	469	$47	1,172	$117
Amarillo	73	1,095	482	$48	1,205	$120
Austin	60	900	396	$40	990	$99
Brownsville	60	900	396	$40	990	$99
Corpus Christi	60	900	396	$40	990	$99
Dallas-Fort Worth	61	915	403	$40	1,007	$101
El Paso	84	1,260	554	$55	1,386	$139
Galveston	62	930	409	$41	1,023	$102
Houston	59	885	389	$39	974	$97
Lubbock	72	1,080	475	$48	1,188	$119
Midland-Odessa	74	1,110	488	$49	1,221	$122
Port Arthur	58	870	383	$38	957	$96
San Antonio	60	900	396	$40	990	$99

The costs associated with using skylights usually are minimal. Utilizing them often only requires that the lighting system be put on a switch with a photocell, or employee education to turn off the lights when they are not needed. Keeping the skylights clean as part of a preventative maintenance program should also be a practice, and will result in a minimal cost to the plant while maintaining the skylight's effectiveness.

INSTALL POWER FACTOR CORRECTION

By installing power factor correction, a manufacturing plant can avoid penalties charged by electric service providers.

Power factor can be described as the ratio of the real power to the apparent power, as shown in Figure 1 below. The real power is the power that is actually of use to the plant. It is what turns motors, operates lights, and does real work. The apparent power is what the electric utility provides to the plant. The third leg of this triangle is the reactive power, and accounts for inductive losses. These losses mainly relate to energizing the magnetic fields of electric motors in the plant.

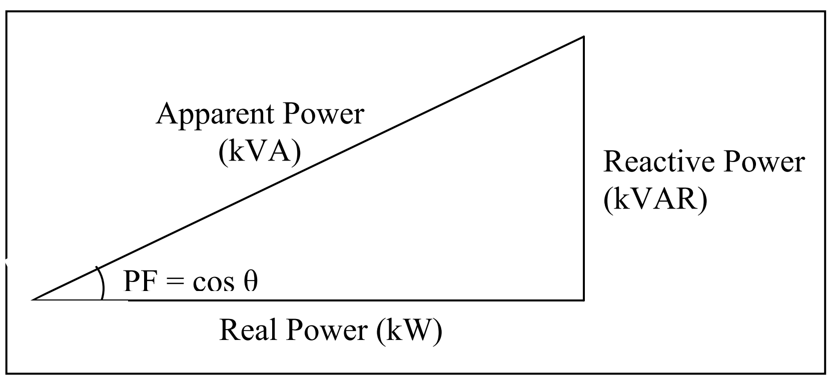

Figure 1: The Power Triangle

When the power factor goes below a certain level set by the electric utility the facility is charged a penalty. These floor levels are typically 85% or 95% for most electric providers in Texas that bill for electrical demand based on kilowatts (kW). This is commonly corrected by installing capacitance to offset the inductive loads. This capacitance may be installed at three main locations in a plant: just inside the utility meter (to correct the problem with a single installation), at various load control centers, or on the terminals of individual machines. The first is the least expensive and most common correction installation. Correcting the power factor causes the reactive power element of the power triangle to shrink, ideally going to zero, bringing the power factor closer to one. Two of the largest electrical service providers in Texas, CenterPoint Energy and TXU, have minimum power factor levels of 95%, while Austin Energy and CPS Energy in San Antonio have floor levels of 85%. Additionally, Reliant Energy penalizes plants for any departure from a power factor of 100% using a different billing approach.

If the power factor at a facility is too low, a licensed electrical contractor or engineer should be contacted to determine how much corrective capacitance is needed. The installer should give assurance that the installation will not exacerbate power quality problems, and that it will be safe for the equipment and personnel in the plant. They should also be able to provide an estimate of annual savings and payback. Since deregulation started on January 1st, 2002, the Texas A&M Industrial Assessment Center has recommended power factor correction be installed at twenty-seven manufacturing plants. The estimated average cost savings at those facilities was $11,700/yr. With an average implementation cost of about $21,000, the average payback is 1.8 years.

CHAPTER IV

CONCLUSIONS

The database of the Department of Energy sponsored Industrial Assessment Center program was used to evaluate the spread in the EUI of different geographic regions and industries. Very large variations in the EUI data resulted when considering two-digit SIC and corresponding three-digit NAICS data, which are common ways of breaking down manufacturing plant data. This trend was corroborated by doing similar analysis with EUIs based on production units instead of plant area. Therefore, caution should be exercised when attempting to extract information for benchmarking when using records of this type. Refining the analysis to narrow the types of plants in a category and being as specific as possible when setting benchmarks improves results.

Additionally, for the centers that were chosen, those in warmer climates had more variability in their data, on average, than those in cooler climates. However, this is perhaps inconclusive because the variations are so large. There are several possible reasons for the large variances in the data, including the grouping of industries with widely differing energy intensity needs in the same category, and various human errors. Several general energy and cost reduction recommendations were also written with Texas manufacturing plants in mind. These “Texas Tip Sheets” are based on some of the most common projects that have been encountered by the Industrial Assessment Center at Texas A&M University. They are meant to be an easily accessible starting point for manufacturers who wish to reduce their energy consumption and are applicable to many facilities.

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